NASA Contractor Report 188427

The Effects of Space Radiation on Flight Film

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ABSTRACT

The Shuttle and its cargo are occasionally exposed to a large enough amount of radiation to create nonimage forming exposures (fog) on photographic flight film. The sensitivity of photographic films to significant space radiation was investigated during several NASA programs including Skylab. Since the films tested on Skylab are no longer used for flight film, the television/photography working group was interested in continuing this study by testing the flight films that are currently in use. The large radiation exposure experienced on STS-31 generated some renewed interest in this area. On that mission, the flight film's (Eastman Kodak High Speed Negative Film 7296 and Ektapress Gold Color Negative Film 5030) exposure to radiation resulted in fogged and degraded images. A test plan was proposed for STS-37. It was later incorporated into Detailed Supplementary Objective (DSO) 318. Flown aboard STS-48, DSO 318 quantified the effects of radiation on spaceflight original films. Specifically, it addressed the effects of significant space radiation on representative samples of six highly sensitive flight films. A lead-lined bag was tested to determine its effectiveness in shielding spaceflight film against the radiation.

The test plan, flown first on STS-37 and then again on STS-48, estimated the level of the film's sensitivity to radiation from the film samples flown. This was accomplished by comparing the photographic characteristics of the flight film to the ground control samples. The flight film samples were placed on the middeck and flight deck for different exposure times to vary the radiation dosage per sample. The estimated difference in radiation levels for each sample was less than 6 percent for STS-48. The resultant characteristics of each sample correlate with this deviation. Consequently, for this mission all flight films used on the flight deck and returned immediately to the airlock had radiation exposure times that were approximately equal. The deviation does not incorporate extended placement in high dosage areas such as the middeck starboard wall and the hatch.

The effects of radiation exposure during STS-48 were apparent in the images produced by the high speed (above 400 ASA) flight films. The color films, such as 7296 and 5030, exhibited an increase in minimum density and a decrease in contrast. Shadows in the images appeared grainy and ambiguous in the darker detail areas. Flatness in the tonal range resulted from the lowered contrast. The black and white films (5454 and 5453) and color negative film (6028) experienced similar effects but to a lesser degree. All the color films exhibited a shift in color balance. These color shifts, along with the increase in base exposure and decrease in contrast, were a function of the representative film speed. While 6028 was the negative film least affected, reversal film 5020 showed the least apparent damage (the maximum density of the reversal film was sufficient to offset the effects of radiation) and was not significantly affected by the radiation.

The shielding bag used in DSO 318 was a lead-vinyl-lined Kevlar bag designed to hold one film sample canister. Both a protected and an unprotected sample were placed in the "Return to Houston Bag" at the start of the experiment. The differences noted between the protected and unprotected sample were used to determine the usefulness of the shielding bag. The bag afforded very little protection from the penetrating space radiation.

Future test considerations and general mission recommendations are presented as a foundation for further investigation into the effects of space radiation on flight film. Further testing of photographic films and shielding configurations will be necessary to not only develop sufficient protection measures but also an understanding of the limitations associated with each.

1. INTRODUCTION

The Shuttle and its cargo are occasionally exposed to a high enough level of radiation to cause nonimage forming exposures (fog) on photographic flight film. This study quantified the effects of radiation on spaceflight original films and evaluated possible protection measures. Specifically, detail supplementary objective (DSO) 318 addressed the effects of significant space radiation on representative samples of highly sensitive flight films used in recent flights. This study also evaluated a lead-lined bag to determine its effectiveness in shielding spaceflight film against radiation.

The space environment contains many types of radiation, most of which are forms of ionizing particles (alpha, beta, proton, etc.). Whether solar or cosmic in origin, these particles release energy while passing through the Orbiter, dosimeters, film, or any other material in their path. This released energy is the catalyst which causes the fogging in photographic film on board the Shuttle.

One of the most damaging effects of radiation on photographic film is an increase in base exposure. It produces higher minimum densities for negative films and lower maximum densities for reversal films. Both types of film experience decreased contrast caused by the changes in minimum and maximum densities. Minimum densities experience proportionately higher fog levels than higher densities, resulting in an additional loss of contrast. Graininess in the shadow regions and compression of the useful density range are also apparent effects of radiation exposure. Color films experience a color balance shift because the separate emulsion layers in a color film, which sensitivities are adjusted for proper recording of different spectral regions of visible light, are affected to different degrees by the energy released from ionizing particles. The most effected layers are blue and green.

This DSO evaluated how well a shielded film bag manufactured by the Allied Glove Company protected flignt film. The bag was designed to hold a single 70 mm cassette (film sample container) and was made of Kevlar material lined with a lead-vinyl and stitched with Kevlar thread. The bag was designed to withstand the same level of x-rays used for airport inspections. The sample protected by the shielded bag was compared to a sample canister which paralleled its test configuration and placement. The bag's level of protection was determined by the difference in the resultant densities of the paired samples.

This process helped to establish the level sensitivity associated with each film type. The reasons why films have an inherit sensitivity to radiation will be discussed in sections one and two. The overview will include shielding considerations and limitations.

1.1 Film Basics

Standard photographic terminology and methods were used in the analysis for this DSO and provide a basis for comparison for the end results. Table I lists and defines photographic terms used to describe the qualities of photographic film. A photographic film's sensitivity to light (exposure) is best depicted on a characteristic curve consisting of the film's resultant densities plotted as a function of log exposure (a.k.a., D log E, D log H, and H & D, named after the originators Hurter and Driffield). The characterisitic curve is a function of the film's densitometric response to exposure and processing (figure 1). For normal processing conditions, the processing variability is kept to a minimum. To produce a sample for this type of evaluation, the film is illuminated through in incrementally increasing exposures (sensitometric exposures). Once processed, the sample is measured using a densitometer to determine the resulting densities. Table II lists and defines the essential components of the characteristic curve.

Table I. Photographic Terminology

Photographic Terms	Definition
Useful Density Range	The breadth of the film's tonal scale available to represent any given image.
Useful Exposure Latitude	A range of film exposure that attempts to encompass the set of luminances reflected in the standard scene. In this case, space scenes.
Average Gradient and Gamma	The response of density as exposure increases, usually corresponding to useful density range, and useful exposure latitude. *Formula : ÆDensity/ÆLog Exposure* *Equivalent terms: Contras and, DynamicResponse*
Speed Point	The specific point on the characteristic curve used to calculate the speed of the film. The speed point is the point of the curve which achieves a proscribed density above the D-min (dependent on the film type, i.e., still color negative and black and white).

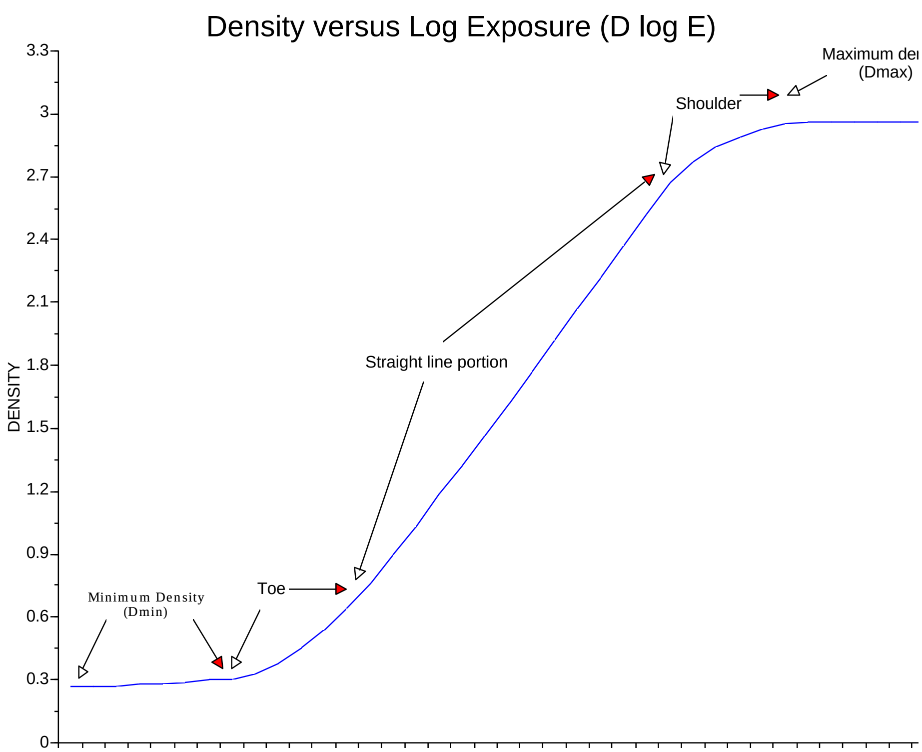

Figure 1. The essential components of the characteristic curve over a six stop range.

Table II. Essential Components of a Characteristic Curve

Essential Components of a Characteristic Curve	Definition	Negative Image	Reversal Image
Minimum Density (Dmin)	Film density that is produced without exposure of any sort. Most photographic processes will develop some silver, resulting in a density change. The region represents the least dense area on the negative. *Equivalent term: Base +fog*	The absolute darkest part of the scene.	The absolute brightest part of the scene.
Toe	The part of the characteristic curve which includes the inflection area following the D-min portion of the curve. This area represents the first distinguishable density increase on the negative.	The darkest area of the scene where strong texture and detail is preserved.	The diffuse highlights of the scene.
Straight Line Portion	This is the central and most linear portion of the curve. Most of the image forming densities makeup this region of the characteristic curve.	The midtones of the scene.	The midtones of the scene.
Shoulder	The zone of inflection between the straight line portion of the curve and the maximum density area. This area usually represents the last highest distinguishable density (before maximum density).	The diffuse highlights of the scene.	When the film density is below 2.5, the shoulder represents the darkest area of the scene where strong texture and detail is preserved. When the density is above 2.5, this description is an addition to the straight line portion.
Maximum Density (Dmax)	Denotes the greatest density achieved by that particular photographic film with respect to the exposure and processing.	The absolute brightest part of the scene.	The absolute darkest part of the scene.

There are some fundamental differences between the properties of negative films and reversal films. Figure 2 shows the general, useful image rendering ranges for negative films. Image colors for negative materials are complementary to the object colors. The most luminant objects produce the densest image on the negative. Lighter objects (e.g., whites and sand) yield dark film images and darker objects (e.g., shadows, tar, and coal) produce light images. In this convention, red objects appear cyan; green objects magenta; and blue objects yellow. Reversal films reproduce light objects as light images and dark objects as dark images. This is consistent with the color representation for reversal films (red objects appear red, etc.). These factors are useful for describing photographic response and are incorporated in this analysis.

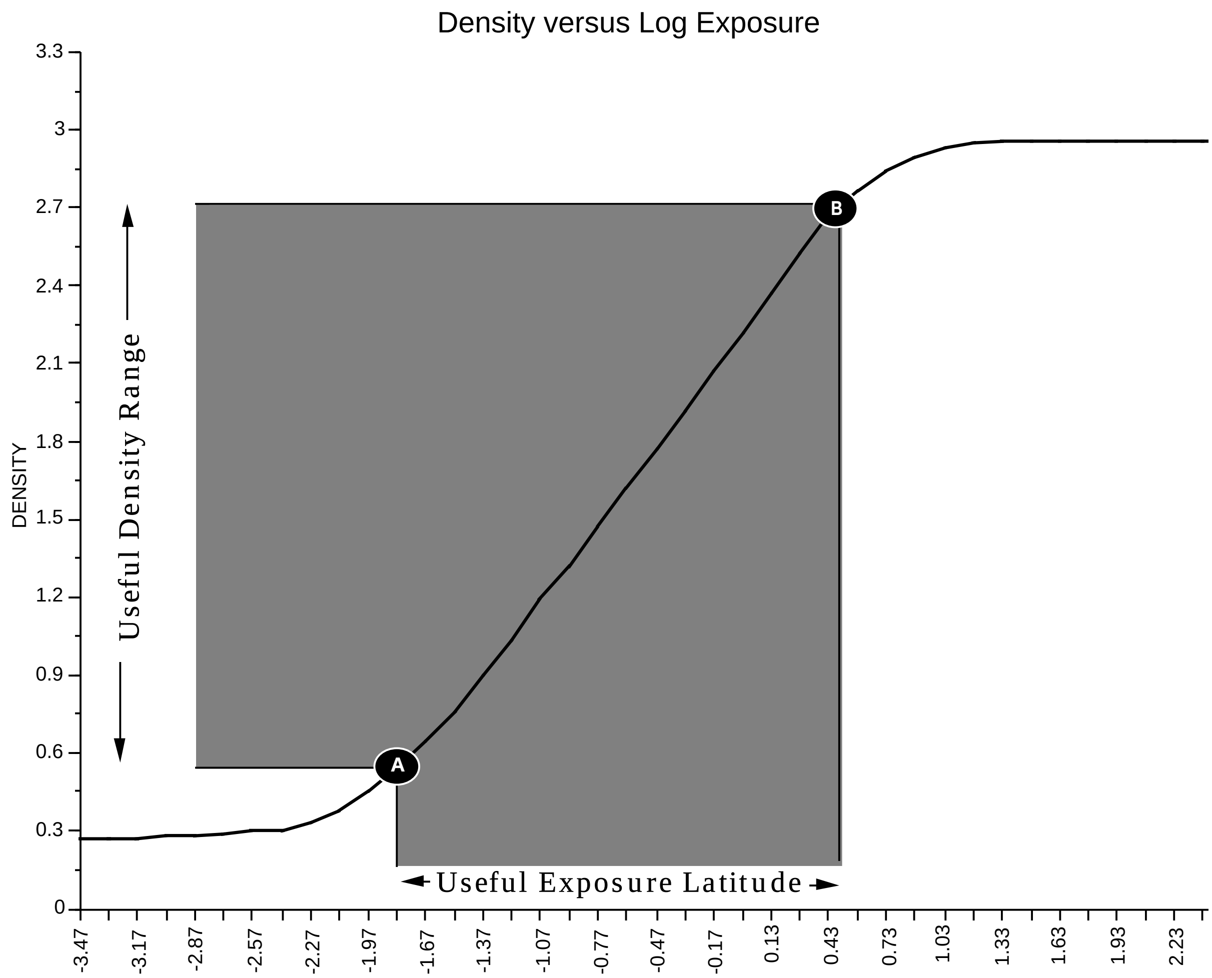

Figure 2. The general useful image rendering ranges for negative films.

1.2 Radiation Basics

Light is a form of radiation and consists of the visible portion of the electromagnetic spectrum. Energy is required to expose photographic films. Although light is a common form of this energy, nonvisible types of energy such as infrared and ultraviolet radiation are also capable of photographic exposure. More energetic radiation, such as x-rays, gamma rays, and assorted ionizing particles, can produce a base exposure on film resulting in increased base plus fog density. Film can be protected from light exposure by enclosing it in a light-free environment. Shielding film from more energetic radiation, however, is not as easily accomplished.

An excellent description of the space radiation environment appears in the introduction of "Guidance on Radiation Received in Space Activities," (Report 98), produced by the National Council on Radiation and Measurements (NCRP). This report states

> "Space Radiation can conveniently be placed into three main categories according to their source: (a) trapped particle radiation, (b) galactic cosmic radiation, and (c) solar particle radiation. The trapped radiation consists mostly of electrons and protons trapped in closed orbits by the earth's magnetic field. The galactic radiation consists mostly of protons, with a small admixture of helium ions and heavier particles. The differences between the last two categories are mainly in the vastly different distributions of particle energies involved and in the sporadic nature of the solar disturbances producing the solar particles as compared with the more slowly varying nature of the galactic particle intensities."[1]

The effects of these categories of radiation can be described by the average amount of energy lost per unit of particle track length through shielding or incident material (e.g., lead, aluminum, and carbon). This effect is called the linear energy transfer (LET). Table III lists the types of radiation and their constituents.

Table III. Radiation Types and Their Constituents

Particle Type	Element Based Ion	Trapped Particle	Galactic Cosmic	Solar
Proton	Hydrogen	Y	Y	Y
Alpha	Helium	Y	Y	Y
Beta	Electron/Positron	Y	Y	Y
HZE	Elements greater than Helium (i.e., Carbon ions and Iron ion)	Y	Y	Y

Of the types of radiation encountered during Shuttle missions, low LET or soft radiation is the most damaging to photographic films. Low LET types of radiation, such as electrons, x-rays, and gamma rays, are more efficient in transferring energy (in the form of photons) to the grains in photographic emulsions. Soft radiation may be described as the least massive particle form of radiation. X-rays and slow-moving ionizing particles ionize during collision and/or interaction with all matter including air. High LET or hard radiation is more penetrating than softer radiation due to the mass and velocities of the particles themselves. Protons, alpha particles (helium ions), heavy ions (heavy Z), and interation products of fast neutrons are examples of hard radiation. This type of radiation is more difficult to shield against. Once they are slowed these particles release energy in incident mediums such as shielding, human tissue, bone, and photographic film. Secondary forms of radiation (daughter radiation) often result from this interaction and can be even more damaging to film than the primary radiation (parent radiation). Ionizing particles are the most abundant source of radiation during Shuttle missions and are the principal cause of photographic damage.

1.3 Radiation Measurements

The rad is the unit used to describe the amount of energy absorbed by any medium. A rad is the absorption of 100 ergs of energy by one gram of the target material (e.g., shielding, human tissue, bone, and photographic film). The more dense the radiated material, the more energy absorbed. Equal incident energies result in different rads of exposure in materials of different densities.

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[1]NCRP Report 98, "Guidance On Radiation Received in Space Activities," Maryland: National Council on Radiation and Measurements, July 1989.

The capacity to absorb energy may be described by the following analogy. When a shotgun is fired at a net (less dense shielding material), most of the pellets pass through the net unobstructed. Although some have their path and speed impaired, very few pellets are completely stopped. By comparison, when a shotgun is fired at a block of wood, the wood stops, slows, or deflects many of the pellets that strike it. Comparing the number of pellets stopped by the respective materials, we find the block of wood has captured more than the net. Furthermore, the number of pellets stopped per gram of material (Rads) is greater for the wood block for equal masses of wood and netting.

1.4 The General Effects of Radiation on Film

Color rendition, tonal response, and image reconstruction are based on the selection and/or grouping of different photographic grains and dye sets (sensitizing and color rendering dyes). Photographically, sensitive grains of silver are the basis of the microscopic image elements evident following processing. These grains have a basic silver halide composition. Silver halide grains require at least two photons to initiate an exposure event. The event consists of energy entering the crystal lattice of the grain and knocking loose an electron. The electron reacts with a silver ion to form a silver metal speck (microscopic subimage element). Once that event occurs three or more times within the grain, the silver halide grain may convert to metallic silver during development. Excess halide ions are trapped in the lattice and/or in the gelatin medium that holds it. If ionizing radiation or particles are introduced into this model, the energy absorbed by the grains may be substantially greater than in typical photographic exposures. This energy can potentially cause many more events than a light exposure, and these events are not limited to a single grain. This would result in more frequent ionizing events and an increase in developable silver metal growth. This exposure results in a density greater than the base plus fog and increases apparent graininess. The large amounts of activity and the nonfocused nature of the radiation result in an even exposure throughout the film.

The ionizing radiation has a range of energies which may encompass equivalent light exposures. When depicted on a density versus log exposure plot, the change in density decreases as the log exposure increases. Those photographic grains with the highest sensitivity (comprising the toe of a nonradiated film sample) are most effected by ionizing radiation. The density increase in the minimum density and the toe is proportionally higher than for those regions of the D log E curve where less sensitive grains comprise the straight line and shoulder (figure 3).

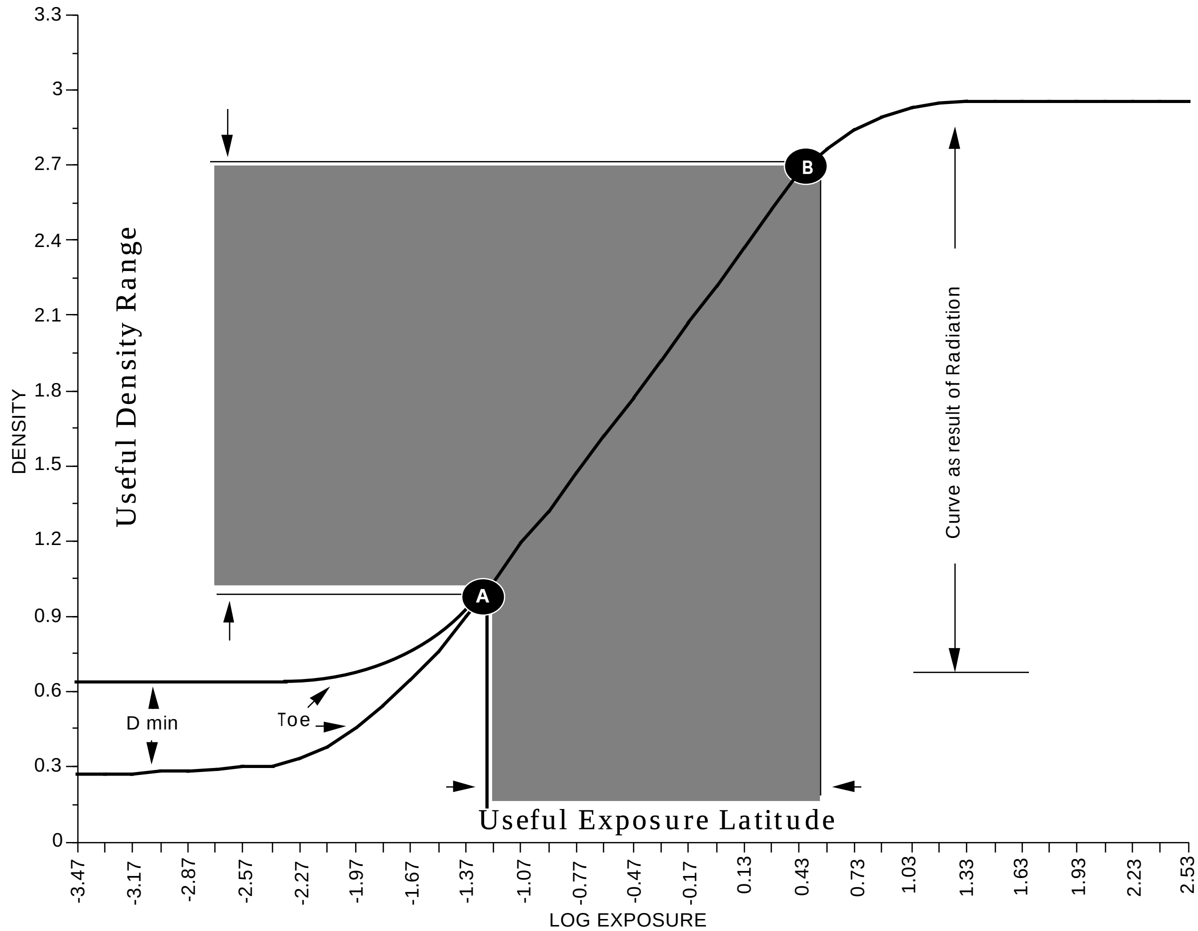

Figure 3. The useful density and exposure latitude for negative film.

1.5 Shielding

Human activities in space require some form of protection to prevent harmful exposure to radiation. Shielding material placed between the radiant source and the vulnerable object is an effective form of protection and can be provided in three ways

- Attenuation - reducing the irradiating energy as a function of shielding thickness
- Collision - reducing particle energy by colliding radiation particles with the more massive shielding elements
- Displacement - reducing the number of energetic particles incident to the vulnerable objects. The density of the shielding material is a major function of this characteristic.

Combining attenuation, collision, and displacement factors results in a decrease in particle number and energy. This translates to a lower radiation dosage incident to the protected item.

Space radiation is very penetrating and difficult to shield against. Protons, alpha particles (A in figure 3), beta particles (B in figure 3) and some high Z particles make up the majority of the radiation encountered during Shuttle missions. Shielding for beta particles is easier to construct than for the heavier particles. A beta particle colliding with an element such as hydrogen (the smallest element) is analogous to a BB shot at a bowling ball. Most shielding elements are at least 12 times as massive as hydrogen and should have no problem stopping beta particles. The more massive radiation particles are more difficult to control. Shielding, which does not stop these particles, will reduce their energy and momentum. Since this type of radiation has a high LET, these particles are more likely to release energy.

During Shuttle missions, the Orbiter, crew, and cargo encounter particles with a wide range of energies, primarily trapped proton and beta particles. Although beta particles do not present a shielding problem for the Orbiter, the proton component of the radiation is more penetrating and not easily stopped. The following steps must be taken to design the shielding necessary to eliminate the photographic fogging caused by radiation:

- Determine the intensity of the trapped particles.
- Determine photographic tolerance to this form of radiation.
- Compute the required reduction in the trapped particle energy.
- Compute the required shield thickness from the reduction factor for variety of possible material types.

The level of radiation experienced on STS-37 was below the damage threshold for the flight film flown, including motion picture film 7296 and Ektapress 5030. If we use that mission as an example of an acceptable dose of radiation, we would be able to calculate the necessary shielding for upcoming missions, provided each mission has a predicted dose. Figure 4 depicts a proton energy profile before and after different thicknesses of lead shielding.

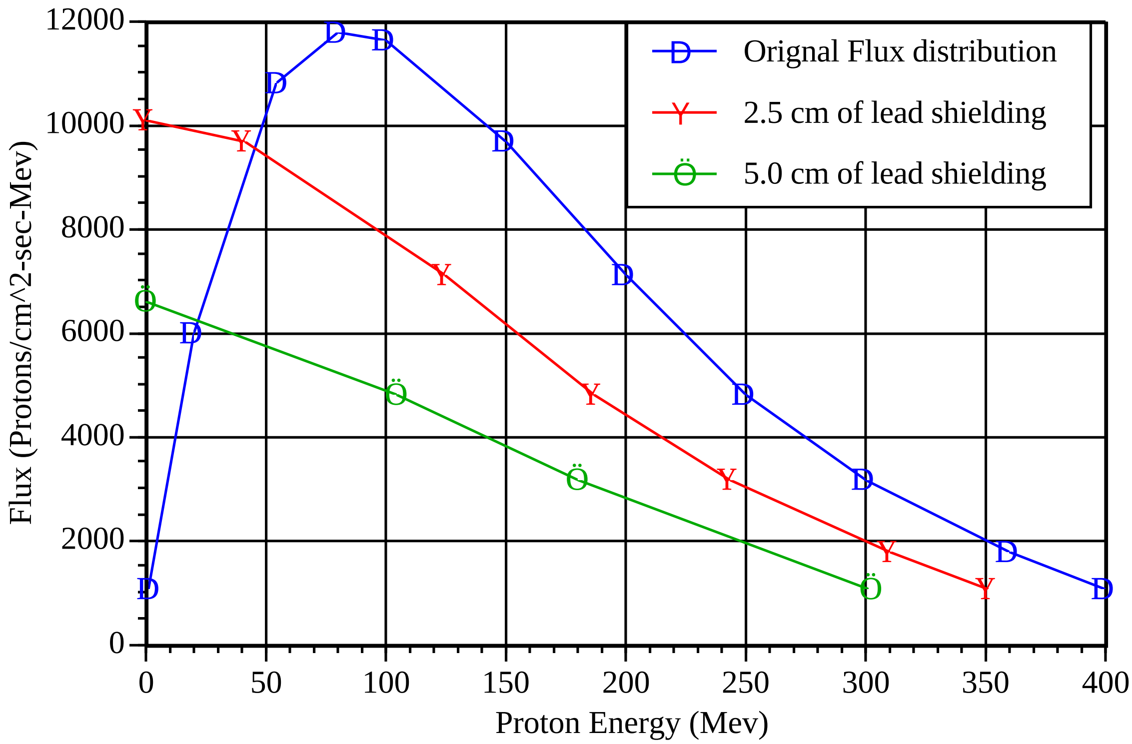

Figure 4. An estimate of the proton flux distribution for a typical Shuttle mission.

The potential number of exposure events caused by the particle bombardment can be minimized by reducing the number of particles. The particles will have the same approximate range of energies after passing through most shielding. If the particle energy profile is greater than the shield rating, the damage would be as bad or worse than if no shielding were present. Determining optimum shielding will minimize the transferred energies to levels which will extend the space shelf life of film. Given sufficient time, even residual and background energies will tend to cause exposure events.

2. THE EFFECTS OF RADIATION ON PHOTOGRAPHIC FILM

The difference in photographic speeds are related to grain size and sensitivity to radiation. As a rule of thumb, the size of the photographic grain is directly proportional to its photon capturing ability. Since faster films have larger grains, they are also more sensitive to radiation. These larger grains comprise the D-min and toe region of the negative film's characteristics. Comparable grains make up the D-max and shoulder of reversal films. The effects of radiation on negative and reversal films are listed in tables IV and V.

Table IV. Effects of Radiation on Negative Films

Characteristic	Effect	Result
Minimum Density (D-min)	The larger, faster grains comprising the area of threshold sensitivity are most susceptible to the impact of charged particles. The particle is ionized which results in a chain of exposure events.	Increased Density - The deep shadow and darker detail is ambiguous in the final image. When printing for whites, the blacks become gray.
Toe	The grains in this region have less response to the radiation because they are not as fast or as large as those in the D-min areas.	Increased Density and Shift in Position - Loss in shadow detail and apparent graininess in the denser areas of the printed image.
Shoulder	The photographic grains in this area are substantially slower than those grains in the D min and Toe region and require more energy to initiate and maintain an exposure event. In terms of light, 100 times more exposure time is required to cause an exposure event in grains representative of the shoulder region than for those found in the Toe.	Unaffected
Maximum Density	The photographic grains associated with this region are not affected for the same reasons as in the shoulder region.	Unaffected
Useful Density Range	As a result of the density increase in the toe and D-min regions, the maximum tonal scale is decreased.	Decreased/Compressed - Image has fewer discrete densities as compared to the object scene. Fewer densities representing the image results in a loss of tonal detail.
Useful Exposure Latitude	The portion of the curve most sensitive to low exposures are unusable after exposure to radiation.	Decreased Exposure Range/Compressed
Average Gradient and Gamma	The declining sensitivity seen in the Toe continues into the straight line portion of the curve. This, combined with the increased minimum density, results in a decrease in the average gradient.	Decreased - The image contrast decreases. There is less tonal discrimination for subtle density changes.

Table V. Effects of Radiation on Reversal

Characteristic	Effect	Result
Minimum Density (D-min)	High exposures are necessary to affect these grains because of their small size and low sensitivity.	Unaffected
Toe	High exposures are necessary to affect these grains because of their small size and low sensitivity.	Unaffected
Shoulder	The grains in this region will have a declining response to radiation because they are not as fast or as large as those found in the D-max areas.	Decrease in Density - Same as maximum density.
Maximum Density (D-max)	The larger, faster grains used at these threshold sensitivities are more prone to impact by incident charged particles, causing the particle to ionize, which in turn, results in a chain of exposure events.	Decrease in Density - Although there is a change in density, the decrease has to be at least a 30% change before it is apparent to the standard observer. Therefore, the standard observer would not perceive a density decrease in the darker regions of this irradiated image. This could become a problem in densities below 2.5 (transmission).
Useful Density Range	A substantial decrease in the D-max can compress the density range, but reversal film's characteristics are very forgiving up to that point.	Virtually unaffected
Useful Exposure Latitude	Same as above	Virtually unaffected
Average Gradient and Gamma	Same as above	Slight decrease

3. PROTECTION

The most common form of protection from radiation is shielding. Shielding protects the sensitive material from radiation (i.e., film) by causing the energized particles to totally ionize into the shielding medium. In cases where shielding is not sufficient to stop all energized particles, the escaping particles will ionize more readily than those particles just entering the shielding. If the radiation intensity is known, the quantity of radiation penetrating the shielding can be determined and its effects predicted. In space, the number of energized particles encountered and their energy states are dependent on the inclination, altitude, and duration of the flight. There is also unpredictable solar activity that can greatly vary the dosage. The question becomes,"what to shield against"? The ideal would be to shield for all energized particles, but that is not a reasonable solution. However, the damage to the photographic materials can be minimized by simply shielding out a large enough percentage of incident particles.

Where the film is located in the Shuttle cabin affects the amount of radiation exposure it receives. Dosimeters are placed in various locations in the cabin to monitor rad dosages to human tissue. The dosimeter recordings show higher dosages on the middeck as compared to the flight deck. This may be attributed to the shielding characteristics of the Shuttle.

The orientation of the Orbiter has also been discussed as a potential means of reducing radiation exposure.[2] When radiation is coming from one direction, as with solar flares, the craft should be able to reduce the radiation dosage by maneuvering its heavily shielded side to the incident radiation. A reduction of approximately 20 percent in the radiation exposure was determined for an appropriately oriented Apollo capsule using a solar flare model.

4. EXPERIMENT PROCEDURE

At the beginning of the STS-48 radiation experiment, all five test cassettes were removed from the film locker. The film cassette stored in the protective bag was placed in the "Return to Houston Bag" along with a nonshielded cassette. These two cassettes were used to determine the usefulness of the shielded film bag and to sample the ambient radiation within the film storage area. The remaining three cassettes were used to determine the life span of photographic materials outside the film storage area. These three cassettes were placed in the overhead window and the mission elapse time (MET) was noted. A cassette was removed from the window and placed in the "Return To Houston Bag" at regular intervals in the MET. For future tests these intervals can be varied according to mission duration, altitude, and inclination.

The crew of STS-48 was instructed to treat the film as regular flight film for initial storage. Upon initiation of the test the canisters were placed in the positions indicated in Table VI.

Table VI. Time Spent by Sample Cassettes in Different Locations

Canister	Location 1	Location 2	Location 4
Can 1	52 hrs. 13 min.	0 hrs.	76 hrs. 14 min.
Can 2	75 hrs. 52 min.	0 hrs.	52 hrs. 34 min.
Can 3	99 hrs. 7 min.	2 hrs.	27 hrs. 20 min.
Can 4	99 hrs. 7 min.	29 hrs. 20 min.	0 hrs
Can 5	99 hrs. 7 min.	29 hrs. 20 min.	0 hrs

The actual rad(tissue) dose recorded per dosimeter location is shown in appendix A. The dosimeter dosages are proportional to the dosage absorbed by flight film. The estimated rad(tissue) absorbed by each canister as related to dosimeter dosages is as follows:

- Canister 1 - 341 mrad
- Canister 2 - 325 mrad
- Canister 3 - 313 mrad
- Canister 4 (Bag)- 363 mrad
- Canister 5 - 363 mrad

Each canister dose equates to

$$\left[\frac{\text{Loc 1 Mission Dose}\ _{(mrad)}}{\text{Mission Duration}\ _{(hrs)}} \text{ X Cannister-time@Loc 1 }_{(hrs)}\right] + \left[\frac{\text{Loc 2 Mission Dose}\ _{(mrad)}}{\text{Mission Duration}\ _{(hrs)}} \text{ X Cannister-time@Loc 2 }_{(hrs)}\right] + \text{..........}$$

[2]Haffner, J.W. Radiation and Shielding in the Space, New York: p. 321, Academic Press 1969.

These estimated rad exposures are summations of the scaled dosages per location at all locations at which the canisters were placed.

5. RESULTS

This DSO typified the effects of radiation on films flown during a particular mission. The six films flown were a representative set of the films found to be sensitive to radiation. These included a color motion picture film, color still negative films, a color reversal film, and black and white still films. Each sample set consisted of seven sensitometrically exposed film strips. Two strips were kept at ambient conditions at the Johnson Space Center (JSC) and functioned as control samples. The remaining five were placed in separate film canisters. Each canister contained one film strip of each of the films tested. The samples flown were

7296 Motion Picture High Speed Color Negative
5030 Ektapress Gold 1600 Professional
6028 Vericolor 400 Professional
5020 Ektachrome P800/1600 Professional
5454 T-Max P3200 Professional
5453 T-Max 400 Professional

These canisters were flown on STS-48, during which the astronauts adhered to the experimental criteria for DSO 318 (appendix B). The 7296 film samples were developed serially using Eastman Color Negative (ECN) chemistry on a Treise Cine-type processor. All other sample sets were developed with the required chemistries in a Colenta rotary processor. The density of all samples was measured and the resultant film characteristics calculated. These values were compared to find the differences between the control and flight samples.

5.1 Motion Picture High Speed Color Negative Film (7296)

Motion picture film 7296 showed an average increase in minimum density of 34 percent and a 15.5 percent loss in the useful density range. The increase in D-min resulted in grainy shadow regions and decreased tonal range for the overall image. The change in color balance would also be apparent to a printer analyzing the negatives. The printer would notice non-neutral highlights and shadows due to the non-uniform compression of the red, green, and blue densities. The decrease in the density range results in a loss of information in the shadow region. These factors are usually taken into account when producing prints and are typically minimized. The graininess in the shadow region and color imbalance in the highlights and/or shadows may be apparent to a standard observer. The results are shown in table VII.

Table VII. Results for 7296 High Speed Color Negative Film

Category Averaged RGB	Averaged Control Sample	Can 1	Can 2	Can 3	Can 4	Can 5
Average Gradient	.53	.45	.48	.48	.47	.47
D-min	.63	.87	.84	.82	.85	.85
D-max	1.83	1.85	1.86	1.85	1.86	1.86
Density Latitude	1.03	.84	.89	.88	.87	.87

5.2 Ektapress Gold 1600 Professional Film (5030)

Eastman color negative film 5030 showed an average increase in minimum density of 30 percent and a 19 percent loss in the average gradient. The increase in the minimum density resulted in grainy shadows. Areas such as dark colored shirts, hair, and shadowed areas around the eyes appeared grainy. These same images seemed "flat", low in contrast, and lacking in tonal response. This "narrowed dynamic response" is a result of the decrease in average gradient (contrast) and density latitude. The change in color balance is also apparent to a printer analyzing the negatives. The printer would notice non-neutral highlights and shadows due to the non-uniform compression of the red, green, and blue densities. The results are shown in table VIII.

Table VIII. Results for 5030 Ektapress Gold 1600 Professional Film

Category Averaged RGB	Averaged Control Sample	Can 1	Can 2	Can 3	Can 4	Can 5
Average Gradient	**.60**	**.47**	**.48**	**.49**	**.51**	**.48**
D-min	**.68**	**.92**	**.89**	**.86**	**.86**	**.90**
D-max	**1.88**	**1.91**	**1.84**	**1.86**	**.1.89**	**1.87**
Density Latitude	**1.01**	**.83**	**.80**	**.84**	**.87**	**.82**

5.3 Vericolor 400 Professional Film (6028)

Vericolor 400 was the least affected color negative film tested. Eastman color negative film 6028 showed an average increase in minimum density of 14.2 percent and a 10.7 percent loss in the average gradient. The slight increase in the minimum density does not cause an increase in apparent graininess as experienced with 7296 and 5030. The contrast decreased somewhat. Images would be "flat" with low contrast and decreased tonal response as a result of the decrease in average gradient (contrast) and density latitude. A change in color balance would be evident but readily correctable during printing. The effects on 6028 are minimal and would not be apparent in secondary products from these originals. The results are shown in table IX.

Table IX. Results for 6028 Vericolor 400 Color Negative Film

Category Averaged RGB	Averaged Control Sample	Can 1	Can 2	Can 3	Can 4	Can 5
Average Gradient	.53	.45	Damaged in processing	Damaged in processing	.47	.50
D-min	.68	.79	xxxxxxx	xxxxxxxx	.77	.77
D-max	1.78	.82	xxxxxxx	xxxxxxxx	.88	.88
Density Latitude	.95	1.76	xxxxxxx	xxxxxxxx	1.78	1.80

5.4 Ektachrome P800/1600 Professional Film (5020)

Ektachrome 5020 is a high speed reversal (slide) film. While the minimum density is most affected in negative films, reversal films are most affected in their maximum density regions. Ektachrome film 5020 showed an average decrease in maximum density of 14 percent and a 11 percent loss in the average gradient. This decrease in maximum density would not cause any noticeable image degradation effect because the resulting density is well above the range of usable densities. Densities above 2.5 are visually and operationally insignificant to the image rendering properties of the film. There was no compression of the density range, so the tonal response of the film was unaffected. The change in color balance would be apparent in the image, but these changes may be compensated for in duplication and printing. The only degradation potentially apparent in 5020 is associated with color balance and would be readily correctable in the printing process. The results are shown in table X.

Table X. Results for 5020 Ektachrome P800/1600 Professional Film

Category Averaged RGB	Averaged Control Sample	Can 1	Can 2	Can 3	Can 4	Can 5
Average Gradient	2.15	1.85	1.92	1.86	1.92	1.96
D-min	.22	.23	.22	.22	.22	.22
D-max	3.36	2.79	2.94	2.88	2.86	2.96
Density Latitude	2.6	2.10	2.18	2.18	2.17	2.24

5.5 T-Max P3200 Professional Film

T-max P3200 black and white film showed an average increase in minimum density of 28 percent and a 3 percent loss in the average gradient. The increase in the minimum density caused an increase in graininess, but the increase was not readily apparent. There was a minimal decrease in contrast that is insignificant. The results are shown in table XI.

Table XI. Results of 5054 P3200 Professional Film

Category (Visual)	Averaged Control Sample	Can 1	Can 2	Can 3	Can 4	Can 5
Average Gradient	.51	.52	.48	.50	.45	.53
D-min	.38	.50	.49	.47	.50	.48
D-max	1.43	1.42	1.43	1.35	1.37	1.43
Density Latitude	.63	.62	.58	.60	.54	.64

5.6 T-Max 400 Professional Film (5053)

T-max 400 black and white film showed an average increase in minimum density of 25 percent and a 5 percent gain in the average gradient. The increase in the minimum density caused an increase in graininess, but the increase was not readily apparent. The contrast had a negligible increase but did not affect image contrast. The slight increase in average gradient has not been accounted for and additional testing is warranted. The results are shown in table XII.

Table XII. Results of 5053 T-Max 400 Professional Film

Category (Visual)	Averaged Control Sample	Can 1	Can 2	Can 3	Can 4	Can 5
Average Gradient	0.52	0.57	0.57	0.53	0.53	0.52
D-min	0.2	0.25	0.25	0.25	0.25	0.25
D-max	0.41	0.51	0.51	0.49	0.51	0.49
Density Latitude	0.75	1.01	1.03	1.00	1.01	0.98

6. CONCLUSIONS AND RECOMMENDATIONS

The effects of radiation for STS-48 are apparent in the final images produced by the high speed (above 400 ASA) flight original films. The color films, 7296 and 5030, exhibited an increase in minimum density and a decrease in contrast. When seen in the final image, shadows would appear grainy and ambiguous in the darker detail. Flatness in the tonal range is the effect of the lowered contrast. The black and white films, 5454 and 5453, and color negative film, 6028, displayed identical effects only to a lesser degree. Reversal film 5020 was not significantly affected by the radiation. All color films exhibited a shift in color balance. The color shifts, increases in base exposure and decreases in contrast, are functions of the film's representative speed. While 6028 was the least affected of the negative films, it should be noted that reversal film 5020 showed the least apparent damage (because the effected part of reversal film is beyond the useful density).

These determinations and observations were made from an analysis of the characteristic curves (D log E plots) of the flight and ground control samples. The D log E plots of 7296 and 5030 plots are examples of the increase in minimum density for red, green, and blue in negative films. Comparing the control plots of 5020 to any of the flight sample plots illustrates the color balance separation.

The results from the STS-48 test are consistent with those from the previous tests performed on STS-37. For example, the compared D-min increase for 7296 flown on STS-37 was half of that measured for the STS-48 samples. This is consistent with the average rad exposure (as per dosimeter readings) exhibited on these flights (STS-37 230 mrad / STS-48 518 mrad). The films flown on STS-37 did not exhibit any apparent image degradation.

The shielding bag does not afford much protection in its present configuration. The bagged sample and sample 5 were compared to evaluate the bag's usefulness. The bag helped 5030 film slightly with a 4 percent reduction in minimum density increase. For most films, the bag afforded no protection. The bag was designed to shield against softer and less penetrating x-rays. However, the film was exposed to high energy particles which passed through the bag quite easily.

Typical mission handling (simulated in the experiment) seemed to keep the film dosages fairly consistent. For evaluation purposes, greater diversity should exist between these dosages. If this study is continued, the film canisters should be placed in the different dosimeter locations for the duration of the mission. This will provide larger rad exposure differences between samples.

Ionizing particles are the most abundant source of radiation during missions and are the principal cause for photographic damage.[3] The effects of high energy particles on flight film would best be quantified through film tests in a cyclotron laboratory (proton models are the best estimate for particle activities). As an option, we could use more accessible forms of high energy radiation such as gamma rays or multi-energized x-rays. These are permissible because the response of the silver halide grain to energetic, singly charged negative particles (secondary electrons from the gamma-ray interaction) and to singly charged positive particles (protons) is essentially the same, provided that the two types of particles have the same LET. Through these evaluations, the response of film to the tested radiation could be correlated to different forms of ionizing radiation. This information could then be used to conduct shielding investigations and to define shielding requirements for spaceflight original films.

The recommendations in this report should be investigated before this test is flown again. If the results of this test are used to select a film dose limit, an appropriate shielding configuration can be determined. Records of radiation doses received during all previous Shuttle flights are available from the NASA Radiation Safety Department. In addition, calculations required to determine the appropriate shielding parameters can be provided by this department. Therefore, the next test iteration should have these shielding considerations discussed and planned in conjunction with the Radiation Safety Department.

The recommendations for Shuttle mission photography listed in table XIII include the merits and limitations of each.

Table XIII. Recommendations for Shuttle Mission Photography

Recommendation	Pros	Cons
Select lower speed films (Speed below 400 films) and use reversal films for missions that have a predicted radiation dose of above 300 mrads. High speed reversal or positive films (Kodachrome, Ektachrome, Fujichrome, etc.) will have little image degradation due to radiation.	Most finer grain films have lower speeds. Finer grain films provide good detail in the captured imagery. Chrome and reversal films have very little image degradation due to radiation (even for film speed above 400). Chrome imagery provides a better mechanism for original duplication and reference color renditions for each particular image. In contrast, the printing of negative imagery relies on the expertise of the color corrector and printing operator for the proper color and tonal rendition of the image.	The lower speed films may not have the necessary exposure latitude for most space photography. Chromes and reversal films are more difficult to properly expose due to their narrow exposure latitude.

[3]Huff K. E. Letter of Correspondence to Mark H. Holly, New York: Eastman Kodak Company October 1990.

Table XIII. Recommendations for Shuttle Mission Photography (Concluded)

Recommendation	Pros	Cons
For purposes of correlation, space imagery and ground sensitometry, frame edge, and leader densities on original flight film can be used as a measure of radiation damage. In addition, some 70 mm film magazines are flown with sensitometric exposures. These magazines could help in correlating the image degradation with that in ground samples. As an extension of this test, a control image may be used with control samples in addition to the flight sensitometry.	Films flown on the Shuttle can be used in comparisons with samples used for certification. A resultant characteristic curve may be extrapolated from this comparison. This will provide a basis to state quantitatively how the film was affected. In addition, the mission imagery can be utilized to qualify the empirical results of the radiation. As a long-term goal, this will aid in building a statistical data base for the response of flight films to radiation. Tools such as this would serve as references of different film's performances in flight and their reaction to space radiation.	Damage from other sources could be associated with exo-radiation (heat, storage, usable shelf life).
On missions above 245 nautical miles, avoid placing flight film in the following areas for extended periods of time: Location 2 - middeck starboard wall Location 3 - middeck hatch Location 5 - flt deck panel above locker L-10 Location 6 - flight deck, panel above locker R-11 Statistically these areas will be exposed with 1.3 to 2.0 times the radiation received by the flight deck observation window (Location 4) or the airlock (Location 1).	By avoiding these areas, the film is more likely to receive a smaller radiation dose than if placed in the other locations.	Avoiding these areas may be difficult due to the close proximity of the dosimeters and compact cabin space.
Photographic films should be stored in the airlock when not in use.	This action will minimize the potential for excessive film exposure to radiation because this location usually has the smallest measured dosages.	Constant film storage and retrieval may be difficult to incorporate into the mission activities.
Alternative processing procedure for irradiated flight film.	Adjusting the processing to compensate for the fogging caused by radiation may improve the duplication characteristics of the original image. This could only be employed when the original imagery exposures are at least consistent throughout the film magazine.	Due to the various exposure situations during a mission, this adjustment in the processing will not be universally advantageous for the varying exposures throughout a single magazine.
Provide simulated images for predicted effects of radiation levels.	Provide an illustrated account of film degradation as a function of predicted radiation level (for visual interpretation).	Limited to equipment and facilities for these exposures and cannot display all possible scenarios.

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APPENDIX A

Excerpt from the NSTS Program Ionizing Radiation Measurement Table

			Measured Dosages per location (mrad)			
Mission	dloc1	dloc2	dloc3	dloc4	dloc5	dloc6
STS1						
STS2	12.50	12.10	11.00	15.00	10.50	10.90
STS3	49.00	46.20	44.40	50.20	44.40	46.00
STS4	45.90	52.50	47.00	47.60	47.10	49.80
STS5	30.70	37.30	29.10	31.30	31.20	35.70
STS6	33.10	34.50	31.50	33.30	35.40	36.90
STS7	46.20	48.90	46.80	43.80	43.20	44.80
STS8	37.50	39.10	39.40	39.90	41.00	40.80
41-A	113.90	122.30	119.60	121.20	119.00	122.10
41-B	53.70	56.10	56.20	60.60	63.70	60.40
41-C	450.00	990.00	767.00	692.00	724.00	740.00
41-D	52.40	63.60	54.40	54.70	59.50	62.90
41-G	83.60	103.10	90.30	88.80	88.50	93.90
51-A	105.80	196.70	131.20	138.50	154.10	157.60
51-C	38.40	43.80	42.40	43.90	51.00	48.50
51-D	329.00	705.00	603.00	534.00	700.00	617.00
51-B	126.00	210.00	230.00	188.00	192.00	162.00
51-G	116.00	185.00	178.00	*****	167.00	162.00
51-F	111.00	183.00	164.00	114.00	127.00	122.00
51-I	93.00	135.00	115.00	110.00	129.00	124.00
51-J	386.00	756.00	623.00	473.00	633.00	577.00
61-A	116.00	154.00	187.00	132.00	140.00	134.00
61-B	130.00	243.00	212.00	180.00	196.00	202.00
61-C	68.00	92.00	88.00	80.00	92.00	95.00
STS26	33.00	37.00	39.70	37.60	41.40	39.40
STS27	165.00	332.00	283.00	215.00	257.00	285.00
STS29	41.30	57.00	59.70	44.60	61.00	52.40
STS30	28.40	37.90	28.50	30.60	31.50	35.70
STS28	62.30	184.50	168.10	71.80	126.00	106.60
	1.20	109.80	95.50	7.90	54.20	35.80
STS34	41.70	40.00	50.90	37.50	53.30	42.80
STS33	507.70	952.90	957.10	598.10	845.70	716.50
STS32	86.30	110.30	91.30	83.10	100.20	107.60
STS36	34.60	33.50	32.90	34.50	34.70	35.50
STS31	860.00	1800.00	1650.00	1100.00	1520.00	1350.00
STS41	19.00	15.00	16.00	18.80	18.20	19.60
STS38	24.60	22.20	23.00	24.10	25.30	22.10
STS35	67.80	97.60	83.80	69.60	79.50	80.20
STS37	150.10	351.80	208.90	193.80	228.50	255.30
STS39	66.30	95.60	85.60	70.20	74.20	71.10
STS40	55.70	103.30	80.20	59.40	79.20	82.40
STS43	40.90	44.70	46.20	44.00	47.80	46.60
STS48	289.30	613.00	726.10	376.70	620.60	487.90

Appendix B

IER-90-12 A Test To Determine The Effects of Radiation on Flight Film

INTRODUCTION

The purpose of this experiment is to collect data on the photographic effects of radiation encountered during Shuttle missions. From the data, we will be able to extrapolate the effects of the radioactive environment on films used for pictorial recordings. In addition, a sample shielding material will be tested to determine its usefulness.

REQUIREMENTS

Five 70 mm cassettes will be loaded with representative samples of negative, reversal, and black and white films which have exhibited acute sensitivity to radiation. Each film sample will be sensitometrically exposed and of sufficient size to support a post mission exposure. The film sample will be spliced, as shown below, to form a continuous roll. The piecewise roll will be wound into a 70 mm cassette (figure 1).

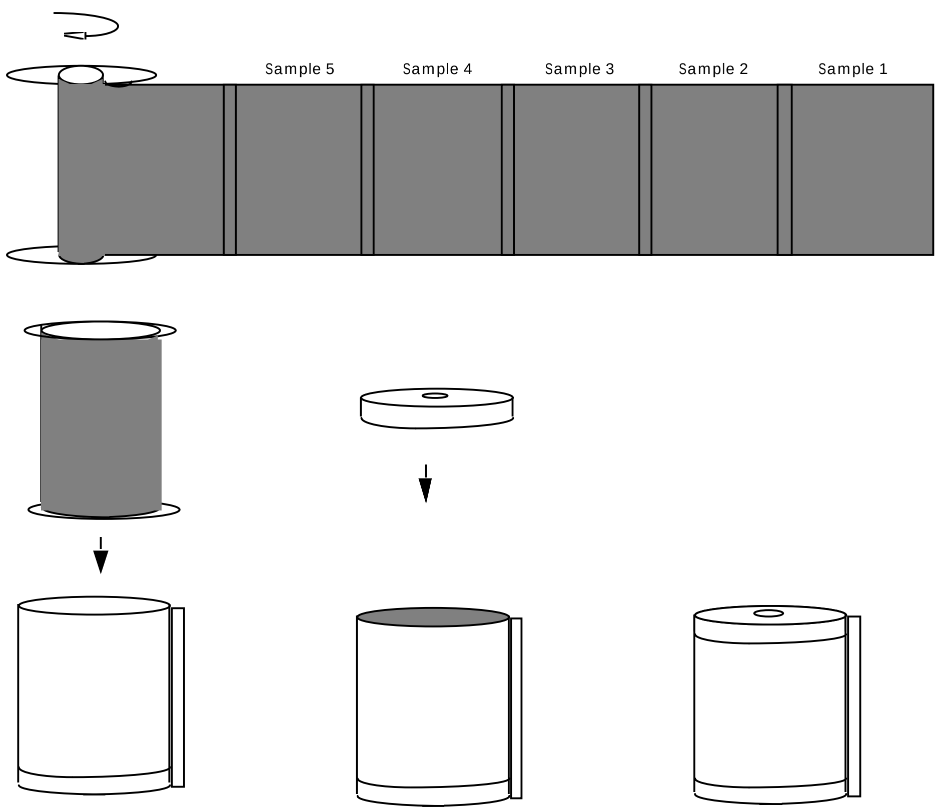

Figure 1

DESCRIPTION

At the beginning of the test, all marked test cassettes will be removed from the film locker. The film cassette stored in the protective bag will be placed in the "Return to Houston Bag" along with a nonshielded cassette. These cassettes will be used to determine the usefulness of the shielded film bag and sample the ambient radiation within the film storage area. The remaining cassettes will be used to determine the life span of photographic materials outside the film locker. The remaining cassettes will be placed in the overhead window, noting the MET (mission elapse time). A cassette will be removed from the window and placed in the "Return To Houston Bag" at regular intervals in the MET. These intervals could be varied according to mission duration, altitude, and inclination (figure 2).

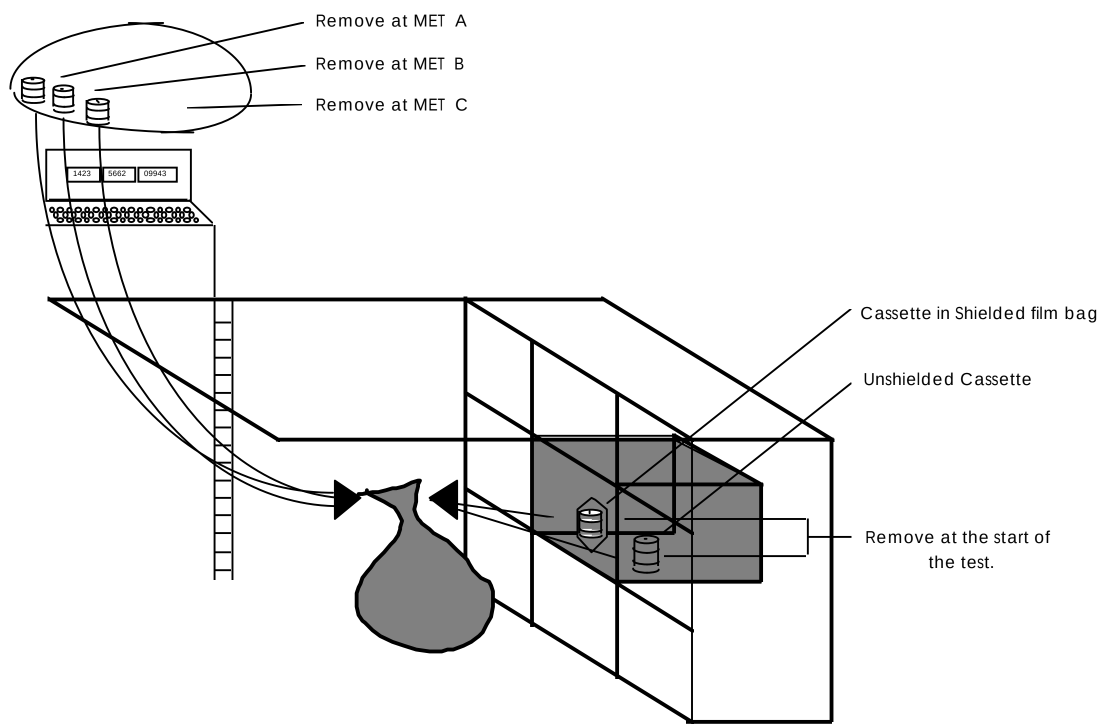

Figure 2